

Meeting the goal of biological integrity in water-resource programs in the US Environmental Protection Agency

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Biological integrity is emerging as an important focus within the US Environmental Protection Agency (EPA) for assessing the condition of the Nation's surface waters and documenting the success of water-resource restoration and protection. This paper traces the concept of biological integrity and its role in EPA's water resource programs and discusses the need for increased collaboration among basic and applied scientists and the government in developing scientifically sound biological measures.

What is biological integrity?

The Clean Water Act of 1972 (CWA) established the objective "to restore and maintain the chemical, physical, and biological integrity of the Nation's waters". However, inclusion of the term "integrity" was long debated. Some legislators felt it should refer to presettlement

conditions. For example, the House Committee on Public Works (US GPO 1972a) defined integrity as a "concept that refers to a condition in which the natural structure and function of ecosystems is [sic] maintained". Continuing, they stated "[o]n that basis we could describe that ecosystem whose structure and function is 'natural' as one whose systems are capable of preserving themselves at levels believed to have existed before irreversible perturbations caused by man's activities". However, other legislators took a more pragmatic view of the term by not defining integrity as a presettlement condition. The Senate Public Works Committee (US GPO 1972b) stated that "The 'natural . . . integrity' of waters may be determined partially by consultation of historical records or comparable habitats; partially from modelling studies which make estimations of the balanced natural ecosystems on the information available". Elements of biological integrity that emerged from

these definitions included: structure and function, sustainability, comparable habitats, and balanced natural ecosystems.

A National Forum on the Integrity of Water in 1975 combined the two Committees' views to describe biological integrity as the "capability of supporting and maintaining a balanced, integrated, adaptive community of organisms having a composition and diversity comparable to that of the natural habitats of the region" (Frey 1977). Further modification by Karr and Dudley (1981) resulted in the widely accepted view that biological integrity can be measured by the "ability of an aquatic ecosystem to support and maintain a balanced, adaptive community of organisms having a species composition, diversity, and functional organization comparable to that of natural habitats within a region". Linking the concept to state water-quality management programs, Karr (1981) recommended that measures of biological integrity be used to assess the degree to which a body of water provides for beneficial uses. It did not take long before these concepts were tested in State programs. For example, Ohio adopted biological criteria in their water quality standards based upon "least impacted" conditions existing within ecoregions (Yoder and Rankin 1995). Maine is also using quantitative biological criteria to assess the ability of their waters to meet their aquatic life standards (Davies et al. 1993).

However, over the past 20 years, the EPA's efforts to protect aquatic life have focused on elimination of chemical toxicity through controls on individual chemicals and whole-effluent toxicity. A great deal of success has been, and will continue to be, achieved through these traditional approaches. But the gains made in reducing the often catastrophic levels of pollution in many waters have revealed other, sometimes more subtle, negative effects on aquatic organisms and their habitats. This continued degradation can be attributed to many factors, including loss of habitat, reproductive defects from bioaccumulative chemicals, manipulation of surface and ground waters, nutrient enrichment from diffuse sources, and introduction of nonindigenous species. Chemical water-quality criteria and whole-effluent toxicity approaches are not adequate to fully protect the biological integrity of water resources and to detect the cumulative and synergistic effects on an aquatic community from all stress-

es. As the EPA and other government agencies embrace the concept of integrated ecosystem protection and management, direct and accurate measures of the condition of the aquatic biota are needed.

EPA's strategic plan and ecosystem protection

The EPA's new Agency-wide Strategic Plan (US EPA 1994) is called the "New Generation of Environmental Protection". This long-term plan will guide planning, resource allocation, and decisionmaking over the next five years (1995-1999). The plan will be driven by seven major principles including two in which biological integrity will play a major role: Ecosystem Protection and Strong Science and Data.

EPA's objective for ecosystem protection is to "upgrade (its) ability to protect, maintain and restore the ecological integrity of the nation's lands and waters, including human health, urban areas, and plant and animal species" (US EPA 1994). To accomplish this, the Strategic Plan states that the EPA must: 1) identify stressed and threatened ecosystems, 2) define environmental goals, 3) develop and implement an action plan, 4) measure progress and adapt management to new information over time, and 5) identify tools and support that can be provided at a national level. A key objective in supporting the principle of strong science and data is to ensure that the Nation's environmental policies are based upon the best science and information available. This will be accomplished by directly measuring environmental progress through ecological indicators, and using the results to improve environmental protection. Biological assessments and criteria are technical tools needed to help meet the EPA's goals over the next five years. Measures of biological integrity clearly have become a priority.

Environmental accountability is also driving the EPA's focus towards biological integrity. The Government Performance and Results Act of 1993 holds the Federal agencies accountable for the tax dollars they receive by requiring 1) strategic plans with long-range goals for all programs, 2) annual budgets, performance plans, and indicators for each program, and 3) annual performance reports that review each program's progress. Two specific EPA initiatives supporting this effort are the development of

environmental indicators and the National Environmental Goals Project.

Biological integrity as a national environmental goal

Over the past two years, EPA's Office of Water has developed four long-range environmental goals and numerous indicators to measure progress towards meeting those goals. One of the goals is the protection and enhancement of aquatic ecosystems. This goal is interpreted as meeting biological integrity and having biologically healthy waters. Indicators for this goal include measures of fish, benthic macroinvertebrates and periphyton, which are used with appropriate chemical and physical parameters to measure whether conditions are suitable for supporting aquatic life (i.e., designated use support in State water quality standards). Indicators reflect the condition, ecological function, and diversity of the aquatic biota.

The Office of Water's goals and indicators are important contributions to the EPA's National Environmental Goals Project, which is designed to produce a set of ambitious, realistic and measurable environmental goals to be achieved by early in the next century (2005). EPA Administrator Carol Browner has made the successful completion of this task a top priority. She believes that government action must be linked to *measurable indicators* of environmental improvement, and that setting goals will inspire cooperation and action by the public. Draft goals and associated indicators will be released for public review by Earth Day 1995.

The Intergovernmental Task Force on Monitoring Water Quality (ITFM) has also recognized the importance of indicators of biological integrity in establishing a national water-monitoring strategy. The ITFM has chosen biological integrity as the topic for a nationwide survey in 1995, and the objective is to answer the question "What is the biological integrity of the aquatic ecosystems in our Nation's Wadeable rivers and streams"? The ITFM (1994) has prepared position papers which cover 1) criteria for the selection of indicators, 2) use of ecoregions, reference conditions, and index calibration, and 3) use of the multimetric approach for describing ecological conditions.

Ecological risk assessment on a catchment scale

Another new activity that supports EPA's strategic plan for ecosystem protection is the shift towards risk-based approaches to evaluation and management of human activities that affect aquatic ecosystems. To meet the challenge of a more expanded environmental focus, the EPA recognizes that better methods are needed to measure, understand, and predict ecosystem vulnerability to many stressors. These assessments must take into account the additive and cumulative effects of chemical, physical, and biological stressors, the dynamic interactions within communities and between the biota and their physical environment, and the need to evaluate risk on a landscape scale, where stressors from one medium, such as air, can transfer to another like water or soil. These are some of the technical challenges facing the EPA as it broadens its focus from regulatory control of individual chemical discharges to addressing combined effects of multiple sources of stress on aquatic ecosystems.

Currently, the process for conducting an integrated assessment of ecosystem risk is not clearly defined, and guidance is unavailable. However, various forms of ecological risk assessments have been used extensively by EPA (e.g., water-quality criteria for protecting aquatic life, pesticide registrations, clean-up levels for hazardous waste sites). The EPA's Risk Assessment Forum has published the Framework for Ecological Risk Assessment to promote consistency when addressing single chemical or physical stressors (US EPA 1992a). The EPA is expanding these basic principles for use in catchment management. Because the ecological status of an aquatic ecosystem is ultimately manifested in the condition and diversity of its biota, measures of biological integrity will be an important component of this risk-based approach for protection and management of water quality.

Biological integrity and water quality criteria and standards

A water-quality standard defines a State's goals for a waterbody by designating the beneficial use or uses to be made of that waterbody and

setting criteria to protect those uses (US EPA 1993b). As mentioned earlier, meeting the designated use for the protection and propagation of aquatic life has often been used in State programs synonymously with meeting the CWA objective for biological integrity. However, because of the EPA's focus on elimination of chemical toxicity, the success or failure to protect aquatic life has been typically reported through measures of predicted or actual toxic impacts of chemicals, e.g., chemical water-quality criteria and whole-effluent toxicity. The effects on aquatic life of habitat alteration, flow regulation, nutrient overenrichment, and the introduction of nonindigenous species, have not been addressed within EPA's traditional water-quality criteria and standards program.

There are at least two immediate needs in the EPA's criteria and standards program for the protection and propagation of aquatic life. First, chemical criteria and whole-effluent toxicity tests are surrogate measures for assessing the status of aquatic biota. A scientifically defensible method to directly measure the condition of the biota is needed to help evaluate the effectiveness of pollution controls and to measure progress towards meeting the CWA objective of biological integrity. Are our actions making a difference? Are further actions needed?

Second, individual point-source discharges are only one source of stress to aquatic biota. Methods are needed to assess the effects of other stresses. Are we protecting aquatic biota from all sources of stress? Are we targeting our actions and resources appropriately?

To help answer these questions, EPA's Office of Water is supporting the development of biological criteria for use in State water-quality protection programs. Biological criteria are defined as "either narrative expressions or numerical values that describe the reference biological integrity of the aquatic biota inhabiting waters of a designated aquatic life use" (US EPA 1990, 1992b). By providing a direct, scientifically sound measure of the condition of the aquatic biota, biological criteria can be used to comprehensively measure the cumulative effects of sources of pollution affecting the aquatic community, including those effects not addressed under the traditional chemically oriented programs. These criteria can be used as quantifiable endpoints to help assess whether

we are protecting and restoring the ecological integrity of our waters and thus fulfilling a critical function in the EPA's adoption of an ecosystem approach.

National guidance has been published that establishes the framework and basic principles for development of biological criteria and their application in water-quality standards (US EPA 1990, 1992b). This guidance will be supplemented by technical documents on the development of biological criteria for the following types of waters: streams and Wadeable rivers, large rivers, lakes and reservoirs, estuaries and near-coastal waters, and wetlands. These documents are developed in conjunction with academic and other federal, state, and Indian tribal experts and will recommend assessment methods and describe the development of biological criteria and their application. The States and Indian tribes then develop, validate, and refine biological criteria appropriate for their waters.

Because biological systems are complex, measures of biological integrity may reflect biological conditions from genetic to individual, community, and landscape levels and include evaluations of both the elements (species richness and identity, genetic diversity, community types) and the processes (individual metabolism, population distribution and dynamics, and community function) that are critical to an abundant and diverse biota. The initial development of biological criteria has focused on selected parameters of community structure and function such as species diversity, trophic composition, and abundance or biomass, each of which conveys a different aspect of the biological condition. These parameters, or metrics, are combined into biological indices to form an integrated, multi-faceted representation of a stable aquatic community for a particular type of surface water. Depending on the type, biological indices can include measures of fish, plankton, benthic invertebrates, vegetation, and amphibians.

Technical issues in the development of biological criteria

The keystone to developing biological criteria is defining the reference condition because

it describes the baseline against which test sites will be evaluated. Depending on State goals for a body of water, the reference condition could represent pristine, "minimally impaired" or "least impaired conditions". The EPA recommends four approaches to establishing reference conditions: use of reference sites; use of historical data; use of empirical models; and use of expert opinion. Reliance upon any one of these approaches or some combination will vary depending upon site-specific conditions and the availability and quality of data. Technical and practical issues of concern span a range between understanding the natural variability (spatial and temporal) within an aquatic ecosystem to protecting a reference site from degradation due to human activities. Some specific issues on defining reference condition include: (1) correctly classifying reference and test sites based on their abiotic characteristics; (2) establishing the range of conditions characteristic of a minimally disturbed reference site; (3) defining reference conditions for regions where most, if not all, water resources have been altered; (4) adjusting for bias (e.g., management or sampling objectives) inherent in historical data sets; (5) detecting degradation of reference sites due to human activities; and (6) determining how to address introduced species.

A clear definition of objectives is critical in designing biological monitoring to develop and, ultimately, implement a program for State biological criteria. The study design includes selecting the aquatic assemblages, resolving technical issues associated with the ecology and appropriate sampling of these assemblages and the analysis and interpretation of the data, and establishing standard operating procedures. Technical questions that must be addressed in the study design include: 1) site selection and sampling regime (temporal and spatial); 2) determination of habitats to be sampled; and 3) establishing the ecological meaning of statistically significant changes in the biological measures.

Scientists from EPA's Office of Research and Development, other Federal and State agencies, and academia have helped the Agency to address the above issues and provide recommended methods for the development of biological criteria. The EPA's Science Advisory Board, composed of scientists from basic and applied fields, has provided critical comment as the program has progressed (US EPA 1993b).

However, more is required to ensure that the types of biological assessment and criteria developed by the EPA and other Federal and State agencies are scientifically sound and practical, reflect recent advances in ecology and biology, and are appropriately understood and applied by decision makers.

Formal public comments on all draft technical guidance documents are planned, including widespread review by scientists. The first technical guidance document on biological criteria (streams and wadeable rivers) is currently undergoing this review. Forums and special workshops on biological assessments and criteria have been held at technical and scientific conferences, including those sponsored by the North American Benthological Society. These efforts should continue to take place. Further definition and discussion of issues will assist in developing and promoting scientifically sound biological measures for protecting and managing water resources.

Concluding remarks

Discourse with academic and government scientists to review methods for biological assessment and criteria is crucial to shaping the EPA's measures of biological integrity. The EPA will place greater reliance on indicators of biological integrity as it rethinks and redirects its programs to achieve integrated protection of aquatic ecosystems. The timeliness, challenges and opportunities for collaboration have been aptly discussed in the opening papers for the BRIDGES series (Hart 1994, Courtemanch 1994). We wholeheartedly support the call for increased collaboration among applied and basic researchers in academia and government.

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